



Photo by Matthew Bradley, Middlesex County

CASE STUDIES IN SEA LEVEL RISE PLANNING

PUBLIC ACCESS IN THE NY-NJ HARBOR ESTUARY

September 28, 2012

Prepared for:

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Pollution Control Commission
(NEIWPCC) and New York-New Jersey
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R2-0015310

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1 EXECUTIVE SUMMARY

The NY-NJ Harbor Estuary is a complex ecological system in the middle of a major urban center. This harbor is the most urban estuary in the nation; accordingly, there is a delicate balance between aquatic habitats and diverse human uses. Any changes to the system or the impact of additional stressors affect the aquatic resources significantly. In response to increasing pressures on coastal communities from sea level rise (SLR), and increasing pressures on public access in the Estuary, the New York-New Jersey Harbor & Estuary Program (HEP) was awarded a grant from the EPA Climate-Ready Estuaries office to focus on site-specific impacts at public access sites in New Jersey.

The contractor, Great Ecology, conducted the technical aspects of the project that are detailed in this report - site-specific vulnerability analyses, development of a Coastal Vulnerability Index, and assessment of resiliency options. This report documents the methods and results of the analysis of the vulnerability of public access infrastructure and natural resources (e.g., parks) to SLR at three public access sites within the New York-New Jersey Harbor Estuary, and the recommendations for steps that could be taken to build resilience at each site.

The project team focused on the Raritan River in New Jersey for the SLR vulnerability analysis. New Jersey is a coastal state, encompassing 127 miles of Atlantic coastline and nearly 1,800 miles of estuarine shoreline, making it especially vulnerable to SLR. A majority of New Jersey's coastline is concentrated with residential, industrial, and tourism-based development (NJDEP 2011). Approximately eight (8) million people live within the coastal counties of New Jersey, and these numbers increase dramatically during the summer months as people take vacations along the shore (NJDEP 2011). New Jersey's coast supports the state's economy through tourism, shipping, recreation, commercial fishing, and aquaculture. The shore is also highly vulnerable to shallow coastal flooding, erosion, and storms (NJDEP 2011).

Three public access sites along the lower Raritan River were selected for analysis. A public access site is defined as a publicly owned area supporting access to the waterfront, into the water, and/or access to docking/landing from the water. These sites—all of which are located in Middlesex County, NJ—were selected because they represent a variety of shoreline conditions and public access infrastructure components. Two existing parks were assessed, one located along the Raritan River (Donaldson Park) and one along the Raritan Bay (Old Bridge Park). The third site is currently under development (Woodbridge Waterfront Park), and provides an opportunity to consider recommendations before the site designs are actually implemented.

A geospatial composite overlay model was used to produce a Coastal Vulnerability Index (CVI) model (adapted from Tallis et al. 2011) to assess SLR impacts in the NY-NJ Harbor Estuary for these three sites. The CVI model was used to evaluate SLR vulnerability based on six (6) criteria: geomorphology, relief, low-lying areas, natural habitats, soil type, and projected sea level rise. Three of these criteria (relief, low-lying areas, and projected sea level rise) are related to elevation, indicating the importance of topography and landscape position of a site in determining its vulnerability to SLR. The CVI model incorporated desktop-based, GIS analysis with field accounts to determine which sites, and even areas of sites, are most susceptible to SLR.

Values were assigned to the key variables of the CVI using a 1 to 5 scale (Gornitz 1990; Hammer-Klose and Thieler 2001), where 1 indicates a low contribution to coastal vulnerability of a particular key variable for the studied area, and 5 indicates a high contribution. Using the ESRI raster calculator function, the final variable values were combined into a single index, adding variable scores together where they spatially overlap to derive the CVI score and model output. Areas with a higher score are considered more vulnerable to SLR. To understand differences between the CVI scores for each site, the mean, standard deviation, maximum, and minimum CVI scores across each

site were calculated. Analysis of variance (ANOVA) was used to determine statistically significant ($P < 0.05$) differences among mean CVI scores.

Based on data gathered during site assessments and results from our CVI model, site-specific and regional recommendations were provided for minimizing potential ecological and public access infrastructure damages from SLR for the three public access sites:

Donaldson Park

- Consider planting additional trees and dense native vegetation along the shoreline to promote soil and sediment stabilization and prevent further bank degradation and soil erosion (Section 4.1.4);
- Institute management practices that promote the maintenance of the shoreline habitats (e.g., limit mowing operations near these areas; Section 4.1.5) and
- Consider planting a dense vegetative border along development boundaries (e.g., stormwater outlets and pathways) to stem impacts and erosion from stormwater runoff at higher elevations (Sections 4.1.2 and 4.1.5).
- Consider locations and assess safety of above ground power lines currently at the edge of the park.
- Incorporate a likely longer-term loss of land surface area at Donaldson Park into planning and maintenance decisions related to public access. When conducting regular maintenance or replacement of existing infrastructure (such as the paved parking lots near the riverbank) in low-lying areas, review any damage that has occurred as a result of flooding events and consider options for replacements at higher elevations to both prevent further damage and allow for upland migration of shoreline habitat.

Old Bridge Park

- Remediation of the existing seawall presents a unique opportunity to redesign the interface of the park with Raritan Bay. Alternatives to replacing the contaminated seawall, such as soft methods of bank stabilization and wetlands restoration, should be considered for the site to increase habitat value and further resilience to SLR (Section 4.2.4);
- Portions of Route 35, the main access road to the park, and the surrounding community of Laurence Harbor, may be impacted by SLR (**Figure 21**). Further analysis of this area should be completed and efforts to mitigate these impacts should be undertaken; and
- Groundwater and contaminant transport modeling should be incorporated into future park planning and coordinated with the EPA Superfund Office to understand the impacts of SLR for areas of the site that are contaminated by lead (Section 4.2).

Woodbridge Waterfront Park

- The public access component of this project has yet to be designed, beyond the conceptual level. Parking areas, trails, and boardwalks should have finished grades that are reflective of predicted SLR elevations. Additionally material choices will be influenced resistance to anticipated inundation and salinity, which will not be present at the time of construction.
- Incorporate plant species that tolerate of a wider range of conditions, to create resilience in the design;

- Identify opportunities for upland transition to provide SLR-related migration of coastal wetlands (Section 4.3.2); and
- Verify that SLR is considered in remedial activities to prevent exchange of contaminants between groundwater, soil, and sediments (Section 4.3.6).

In addition to site-specific recommendations, we also provide a regional assessment and recommendations.

This report is intended as a tool for governments, agencies, practitioners, and coastal decision-makers seeking to assess and plan for SLR. The Coastal Vulnerability Index model approach used in this study demonstrates a relatively simple and rapid method that provides coastal communities with the information needed to mitigate and plan for SLR. Our work provides a useful and reusable framework for assessing SLR vulnerability and resilience at the local (site) geographical scale.

2 BACKGROUND

Coastal communities across the globe are concerned with the potential risks associated with elevated sea levels. Climate change is expected to contribute to an increase in global mean sea level during this century and beyond (Church et al. 2001; IPCC 2007; Horton et al. 2010). Accelerated SLR will render coastal communities and ecosystems increasingly vulnerable to permanent inundation of low-lying areas, inland extension of intermittent flooding, increased shoreline erosion, and saline intrusion of aquifers (McLean et al. 2001; Cooper et al. 2008).

Two processes contribute to SLR: the melting of land-based ice that increases the volume of ocean water, and thermal expansion (as water warms; it expands, NOAA 2012). Other geomorphic changes, such as the process of sea floor spread, erosion, and subsidence also play a role. As global climate change continues to increase sea levels and increase the frequency and severity of coastal storms, more people, developments, and natural resources will be vulnerable to the impacts of coastal hazards.

Due to the combination of climate change and regional subsidence, the sea level in New York and New Jersey is rising faster than the global average. The New York Panel on Climate Change predicts between 7 to 12 inches of SLR by the 2050s and 12 to 23 inches by the 2080s (excluding rapid ice melt scenarios; IPCC 2007).

Natural resource managers and planners are currently focused on assessing the impacts of SLR to determine which areas are most vulnerable. Federal and state policies now strongly mandate coastal construction standards and flood prevention ordinances for local governments to secure mitigation funding (NJDEP 2011). Coastal communities are taking proactive measures to improve their resilience through land use planning, public education, and disaster preparedness in response to SLR risks. In addition, the New Jersey Department of Environmental Protection (Office of Coastal Management) has conducted a Coastal Community Vulnerability Assessment Pilot (CCVAP) in multiple communities in New Jersey, focusing on the broad scale impacts to towns. As a result of SLR, public access to the estuary and waterfront is currently limited, and is likely to become increasingly so, as areas are damaged or flooded, and municipal and federal capital for repairs are depleted. In response to this increasing pressure, the NY-NJ Harbor & Estuary Program launched Case Studies in Sea Level Rise Planning, using a grant from the Environmental Protection Agency and working in partnership with New England Interstate Water Pollution Control Commission and Great Ecology.

Program Background: The NY-NJ Harbor & Estuary Program is one of 28 National Estuary Programs across the United States and focuses on protecting and restoring healthy waterways and productive habitats, managing sediments, fostering community stewardship, educating the public, and improving safe access to our waterways. The program is supported by both employees of the Environmental Protection Agency (EPA) and the New England Interstate Water Pollution Control Commission. and is a partnership of civic and environmental leaders; federal, state, and local governments; non-governmental and community organizations; scientists, educators, boaters, and other interested individuals focused on restoring and protecting the waterways and habitats of the New York-New Jersey Harbor Estuary. The NY-NJ HEP maintains a core area of focus on the estuarine waters of the Hudson-Raritan Estuary, but its geographic footprint includes the Hudson River watershed up to the Troy Dam, as well as the watersheds of the Raritan, Passaic, and Hackensack Rivers in New Jersey (<http://www.harborestuary.org/geography.htm>).

The NEIWPCC is a not-for-profit interstate organization established by Congress in 1947 to meet the water-related needs of its member states – Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. The NEIWPCC serves and assists its member states by

coordinating activities and forums that encourage cooperation among the states, developing resources that foster progress on water and wastewater issues, representing the region in matters of federal policy, training environmental professionals, initiating and overseeing scientific research projects, educating the public, and providing overall leadership in water management and protection.

3 METHODS

3.1 Site Selection and Background

The project team focused on New Jersey for the SLR vulnerability analysis. New Jersey is a coastal state, encompassing 127 miles of Atlantic coastline and nearly 1,800 miles of estuarine shoreline, making it especially vulnerable to SLR. A majority of New Jersey's coastline is concentrated with residential, industrial, and tourism-based development (NJDEP 2011). Approximately eight (8) million people live within the coastal counties of New Jersey, and these numbers increase dramatically during the summer months as people take vacations along the shore (NJDEP 2011). New Jersey's coast supports the state's economy through tourism, shipping, recreation, commercial fishing, and aquaculture. The shore is also highly vulnerable to shallow coastal flooding, erosion, and storms (NJDEP 2011).

Analysis was specifically focused on the areas adjacent to the Raritan River because its basin is the largest in New Jersey and is highly utilized for residential, industrial, and recreational activities. Tributaries of the Raritan River cover more than 1,100 square miles of land and ultimately drain to the Raritan Bay in the NY-NJ Harbor Estuary (Shaw et al. 2009). Raritan waters supply drinking water to more than one (1) million New Jersey residents and flow through more than 100 municipalities. The Raritan River Basin includes large areas of urban, agricultural, and forested land, with significant areas of wetlands. The Raritan River also is a popular source of recreation. More than 200 public recreation sites and protected areas are located within the Raritan River Basin, totaling more than 50,000 acres (NJWSA 2002).

The Raritan River originates from two sources and forms two branches: the Upper Raritan and the South Branch, which converges at Branchburg to form the Lower Raritan (Shaw et al. 2009). The Lower Raritan is the main stem of the river and the primary focus of our analysis. The study area for this report was confined to the approximate influence of tidal waters, the estuary in lower Raritan from New Brunswick to Old Bridge, located in the Raritan Bay (**FIGURE 1**).

Three public access sites along the lower Raritan River were selected for analysis. A public access site is defined as a publicly owned area supporting access to the waterfront, into the water, and/or access to docking/landing from the water. These sites—all of which are located in Middlesex County, NJ—were selected because they represent a variety of shoreline conditions and public access infrastructure components. Two existing parks were assessed, one located along the Raritan River (Donaldson Park) and one along the Raritan Bay (Old Bridge Park). The third is currently under development (Woodbridge Waterfront Park), and provides an opportunity to consider recommendations before the site designs are actually implemented.



**GIS MODEL REGIONAL OVERVIEW
LOWER RARITAN RIVER**

NY-NJ HARBOR ESTUARY PROGRAM
SEPTEMBER 2012

0 0.5 1 Miles

 **GREAtEcology**
ENVIRONMENT + DESIGN

FIGURE 1
1:90,000

NAD 1983, UTM Zone 18N

3.2 Compiling Site Accounts

Site visits and field verification of GIS data were conducted at the Donaldson and Old Bridge Park sites. Site visits included presence/absence surveys of barriers to any upland migration for wetlands (e.g., pavement, seawalls), condition of hard shore structures (e.g., seawalls, boat launches, bulkheads), and qualitative observations of level of repair (if needed). The presence of public access structures (e.g., boat ramps, piers, picnic tables, pavilions, trails, ball fields, restrooms, etc.) was recorded on datasheets and their location was recorded on aerial photos. In addition, observations of the riverbank slope, habitat composition, and geomorphology were documented for inclusion in the CVI model.

3.3 Coastal Vulnerability Index Model

A CVI model was developed to conduct the SLR analysis. This method provides a simple numerical basis for ranking sections of coastline in terms of potential for change. Results of this model can be used to identify areas of higher SLR risk (Gornitz et al. 1991). Results are displayed on maps to highlight regions where there are factors that contribute to SLR vulnerability (Gutierrez et al. 2009).

3.3.1 GIS Development

A literature search for GIS models that estimate SLR using LiDAR data on the east coast of the United States was conducted. Based on this literature review, six variables (as described in Gornitz et al. 1991) were identified as the primary factors influencing SLR vulnerability: 1) geomorphology, 2) relief (percent slope), 3) the extent of flood-prone (low-lying) areas, 4) the extent of natural habitats (land use/land cover data), 5) soil drainage/hydrology, and 6) sea level change (Table 1). Each of these variables contributes towards making an individual site more or less susceptible to impacts from SLR. These variables are detailed in the Coastal Vulnerability Index Variables subsections that follow.

Table 1: Coastal Vulnerability Index Variables

	Data Layer	Definition	Data Source	Resolution	Data Verification Method	Data Acceptance Criteria
1	Geomorphology	Physical characteristics of shoreline and adjacent areas	Created dataset from field assessments of sites	30m	Verified in field	Verified presence/location in field
2	Relief (percent slope)	Slope of surface topology	Created dataset from NOAA LiDAR DEMs	5m	Verified in field	Verified accuracy in field
3	Flood-Prone (low-lying) Areas	Areas below mean sea level at varying increments of SLR (1 to 6 feet)	NOAA Analysis of LiDAR DEMs	5m	Comparison to known surveyed elevation data	0.6 feet (18.5 cm) root mean square error (RMSE) for low relief terrain, 1.2 feet (37.0 cm) RMSE for high relief terrain

Table 1: Coastal Vulnerability Index Variables

	Data Layer	Definitlon	Data Source	Resolution	Data Verificatio n Method	Data Acceptance Criteria
4	Natural Habitats	Currently existing land use and land cover types	NRCS Land Use/Land Cover National Dataset	30m	Comparison to aerial photography and field verification	Data updated every 5 years, most current publication 2006
5	Soil Drainage/ Hydrology	Drainage class of soils	NJDEP SSURGO, aerial photography analysis	1:24,000	Metadata, onsite observations of drainage structures	Created/ Updated within past 10 years
6	Sea Level Rise	Areas inundated with water at varying levels of SLR (1 to 6 feet)	NOAA LiDAR DEMs	5m	Comparison to known surveyed elevation data	0.6 feet (18.5 cm) root mean square error (RMSE) for low relief terrain, 1.2 feet (37.0 cm) RMSE for high relief terrain

3.3.2 Coastal Vulnerability Index Variables

3.3.2.1 Geomorphology

Site geomorphology describes the physical characteristics of the shoreline and adjacent areas within the CVI model. Aerial photos were interpreted for geomorphic shoreline composition and qualitative assessments were conducted in the field for classification verification (i.e., seawall, sandy beach, cliff, and mudflat). Steep, rocky cliffs are less prone to erosion than bluffs or sandy beaches (Tallis et al. 2007). We used a geomorphologic ranking of values that is similar to the one proposed by Hammar-Klose and Thieler (2001); rocky shorelines, high cliffs, or large seawalls received a low vulnerability score; whereas, areas of sandy beach and mudflat habitat received a higher vulnerability score ([Table 2](#)).

Table 2: List of Bio-Geophysical Variables And Ranking System for Coastal Vulnerability Index

Rank	Very Low	Low	Moderate	High	Very High
Variable	1	2	3	4	5
Geomorphology	Rocky; high cliffs; large seawalls	Medium cliff; indented coast; bulkheads; small seawalls	Low cliff; glacial drift; alluvial plain; rip-rap walls	Cobble beach; estuary; lagoon; bluff	Sandy beach; mud flat; delta
Relief (percent slope)	>20%	7-20%	4-7%	2.5-4%	<2.5%
Flood-Prone (low-lying) Areas	≤6'	≤5'	≤4'	≤3'	≤2'
Natural Habitats	Coastal forest	High dune; high marsh	Low dune	Intertidal marsh	No vegetated wetland habitat; sandy beach; mudflat

Table 2: List of Bio-Geophysical Variables And Ranking System for Coastal Vulnerability Index

Rank	Very Low	Low	Moderate	High	Very High
Variable	1	2	3	4	5
Drainage (soil drainage characteristics)	Excessively - well drained soils (psammments)	Moderately well- and somewhat poorly drained soils (Rowland)	Very poorly drained soils (Pawcatuck)	Impervious surfaces	Water
Sea Level Rise	6'	5'	4'	3'	<2'

3.3.2.2 Relief (Percent Slope)

Relief refers to the percent slope of surface topology. Relief was calculated using the ArcMap 9.3 slope tool (Environmental Systems Research Institute, Research Triangle, and North Carolina). The slope tool analyzes a Digital Elevation Model (DEM) raster and returns a value equal to the maximum rate of change from each cell to its neighbors. This results in a raster dataset with each cell value representing the relative slope of the area adjacent to it. The mean of the raster values of this dataset was calculated using project location boundaries to determine average slopes per site. During site visits, these calculations were verified through qualitative observations of shoreline slope (i.e., steep, moderate, relatively flat). Areas with lower relief (lower percent slope) were ranked as highly vulnerable to SLR; whereas, areas with a higher relief were ranked as less vulnerable.

3.3.2.3 Flood-Prone (Low-Lying) Areas

Flood-prone areas are low-lying areas within the landscape below Mean Sea Level (MSL). In direct association with the SLR DEMs, the National Oceanic and Atmospheric Administration (NOAA) produces vector shapefiles of low-lying areas that are considered hydrologically *unconnected* (USGCRP 2003). These are areas that may flood and are determined solely by how well the elevation data capture the area's hydroconnectivity (NOAA 2012). Areas that are above MSL are at a lower risk of inundation and are ranked lower within the model; whereas, areas at or below MSL are ranked as more vulnerable (**Table 2**). NOAA DEMs are not available for the future condition of the proposed Woodbridge Waterfront Park, as elevation will change as a result of planned restoration; therefore, for this part of the analysis, we used NOAA DEMs for existing conditions on the site and interpreted these findings using proposed design specifications for the site.

3.3.2.4 Natural Habitats

Natural habitats are areas that have not been directly modified by humans. Great Ecology used aerial photographs and the NRCS Land Use/Land Cover National Dataset (Fry et al. 2011) to determine natural habitat composition and then verified these habitats during field visits. Wetlands can mitigate the effect of coastal hazards by providing temporary floodwater storage in the floodplain, and by attenuating wave energy. However, other natural habitats, including sandy beach, mudflat, and sparsely vegetated habitats, provide little shoreline protection from erosion and inundation. These habitats are ranked as highly vulnerable within the model. Areas of coastal forest, high dunes, and salt marsh are ranked as having a lower vulnerability (**Table 2**).

3.3.2.5 Soil Drainage/Hydrology

Soil drainage is defined within the CVI model as the specific drainage class of the major soil type by site (NJDEP 2008). Soil drainage characteristics are from the New Jersey Department of Environmental Protection (NJDEP) Soil Survey Geographic 2008 (SSURGO) Database for Middlesex County, New Jersey (projected to NJ State Plane Feet, NAD83). Additionally, Great Ecology recorded field notes during site visits pertaining to drainage structures and hydrologic flow patterns observed.

We considered areas of existing water as highly vulnerable, while areas of excessively well-drained soils (psammants) less vulnerable ([Table 2](#)).

3.3.2.6 Sea Level Rise (NOAA LiDAR/DEMs)

Within the CVI model, NOAA remotely sensed data were used, that is, raster SLR layers based on Light Detection and Ranging (LiDAR) data (USGCRP 2003). We examined data representing areas inundated with water from SLR in one (1)-foot increments above mean higher high water (MHHW) from one (1) to six (6) feet. DEMs display the inland extent and relative depth of SLR inundation of areas that are assumed to be hydrologically connected (NOAA 2012). Areas inundated only after six (6) feet by SLR are ranked lower in the model; whereas, areas inundated by one (1) to two (2) feet are seen as more vulnerable and are thus ranked higher ([Table 2](#)).

- NOAA derived DEMs from source elevation data (LiDAR) that met or exceeded the Federal Emergency Management Agency (FEMA) mapping specifications for the National Flood Insurance Program:
 - 0.6 feet (18.5 cm) root mean square error (RMSE) for low relief terrain; and
 - 1.2 feet (37.0 cm) RMSE for high relief terrain.

Areas with elevation data that did not meet these criteria were not included in this study. The NOAA VDatum model adds additional error (RMSE) to the base data that ranges from several centimeters to tens of centimeters, depending on the location. The DEMs used to map SLR in this tool did not incorporate a detailed pipe network analysis or engineering-grade hydrologic analysis (for example, culverts and ditches may not be incorporated, resulting in incorrectly mapped areas NOAA 2012). The NOAA DEMs are not available for the future conditions of the potential Woodbridge Waterfront Park. Therefore, for this portion of the analysis, NOAA DEMs were used for existing site conditions.

3.3.3 Geoprocessing

Raw third-party geographic data were processed to produce a portion of the CVI rasters for the study area. This process is referred to as Geoprocessing. Geoprocessing these data for inclusion in the GIS model included the following three steps:

1. Import raw data and convert vector datasets to raster datasets;
2. Convert raw data resolution to the 30-meter resolution of the GIS model; and
3. Reclassify raw data cell values to the established CVI ranking ([Table 2](#)).

Original geomorphology data were collected in the field using a Trimble GeoXT handheld GPS unit to delineate areas of varying coastal vulnerability. After field visits, data were imported into the GIS model from the GPS unit, geomorphology areas were indexed on general vulnerability to sea level rise ([Table 2](#)), and each geomorphology polygon was assigned a vulnerability index. Using the ESRI Feature to Raster ArcMap tool, a 30-meter by 30-meter resolution raster was converted from the GPS vector polygons to create a raster dataset of CVIs. Geomorphology areas were indexed based on general vulnerability to sea level rise ([Table 2](#)).

The LiDAR elevation data provided by NOAA was used to calculate percent slopes of the study area using the ESRI Spatial Analyst extension of the ArcMap software suite. Slope data were analyzed on a site-by-site basis, where each site's slope characteristics were extracted from the study area slope raster. NOAA data were converted from a 5-meter by 5-meter resolution to a 30-meter by 30-meter resolution raster, and then the mean of cells from the original dataset was taken to produce

corresponding 30-meter cells. Slope criteria shown in **Table 2** dictated the reclassified CVI cell values assigned to the final raster dataset.

Values were assigned to the key variables of the CVI (**Table 2**) using a 1 to 5 scale (Gornitz 1990; Hammer-Klose and Thieler 2001), where 1 indicates a low contribution to coastal vulnerability of a particular key variable for the studied area, and 5 indicates a high contribution. Using the ESRI raster calculator function, the final variable values were combined into a single index, adding variable scores together where they spatially overlap to derive the CVI score and model output. Each cell of the final CVI dataset ranges from a potential high of 30 to a low of 0. Areas with a higher score are considered more vulnerable to SLR; whereas, areas with a lower score are less so.

3.3.4 Statistical Analysis

To understand differences between the CVI scores for each site, the mean, standard deviation, maximum, and minimum CVI scores were calculated across each site. An analysis of variance (ANOVA) was used to determine statistically significant ($P < 0.05$) differences among mean CVI scores.

4 RESULTS

In this section, we present the results derived from our onsite assessment and application of our customized CVI model. It is important to note that for the purposes of this study, the focus was on sustained inundation caused by sea level rise. Other factors, such as storm surge, high tide events, and heavy rainfall are also likely to contribute to periodic flooding events, and should be a potential consideration for planning or future study.

4.1 Donaldson Park

Donaldson Park is positioned along the banks of the Raritan River in the town of Highland Park within Middlesex County (**FIGURE 2**) (**Photo 1**). This area was formerly a riparian zone filled to create athletic fields and public parkland, and contains a man-made pond (HPEC 2012). There are eight parking lots scattered through the park, numerous athletic fields (including four baseball fields, two soccer fields, two basketball courts and two tennis courts), two playgrounds, and two picnic groves (**Photo 2**), to the left and right of the boat ramp. Walking and bicycle paths transect the park throughout. The park has a boat ramp, a floating pier (**Photo 3**), and a large parking lot with parking spaces for vehicle with trailers. Users of the boat ramp must have permits from Middlesex County Parks. The boat ramp is accessible year round, while the pier is removed late fall to early spring (HPEC 2012). Fishing for freshwater and salt-water species of fish occurs both in the adjacent tidally-influenced portion of the Raritan River and in the man-made pond.



Photo 1: Donaldson Park (Photo by Kate Boicourt)



Photo 2: Picnic groves



Photo 3: Boat ramp and floating pier



Photo 4: Man-made freshwater pond



Photo 5: Athletic fields interspersed with a variety of shade trees



Photo 6: Evidence of stormwater erosion and deposition on pathways



Photo 7: Stormwater runoff erosion channel

4.1.1 Geomorphology

Donaldson Park contains approximately 90 acres of managed, open fields. The Park has a riverbank length of approximately 0.7 miles and a 1.8-acre man-made freshwater pond (**Photo 4**). The majority of the park area consists of grass-covered athletic fields, converted from wetland habitat (**FIGURE 3**). Forested habitats and freshwater wetlands are also located within the park boundaries, and the boundary between the park and the Raritan River is mudflats. There are a variety of native and non-native planted shade trees, including Honey Locust (*Gleditsia triacanthos inermis*) and Red Oak (*Quercus rubra*) interspersed throughout the park (**Photo 5**).

4.1.2 Relief (Percent Slope)

Donaldson Park is relatively flat with a mean percent slope of 1.9%. Slopes drop gently from north to south and toward the Raritan River (**FIGURE 4**). This is in stark contrast to the developed areas to the north of the park and the steep cliffs across the river from the park that sits at a higher elevation. The impervious surfaces from the surrounding community and residential areas, upslope of the park, likely contribute to the large amount of suburban runoff observed during the site visit (**Photos 6 & 7**). The elevation of the riverbank along Donaldson Park is not substantial and ranges from approximately 0-12 inches; whereas, the opposite shoreline has steep cliffs ranging from approximately 0-180 feet elevations.

4.1.3 Flood-Prone (Low-Lying) Areas

As a former riparian zone of the Raritan River, all of Donaldson Park is at a relatively low elevation, with a mean elevation of approximately 6.2 feet. A small area at the south of the park is within an unconnected low-lying area (**FIGURE 5**). This portion of the park is at approximately 5.0 feet elevation. During our site visit, we observed standing stormwater in these areas and eroded sediment deposited on walking pathways (**Photo 6**). The Raritan River at Donaldson Park is tidally influenced. The reach of the tide ranges from five (5) to seven (7) feet (HPEC 2012).

4.1.4 Natural Habitats

The majority of the park consists of non-natural habitats classified as developed, open space (namely manicured lawns and athletic fields, **FIGURE 6**). At low tide there are large mud and gravel flats (**Photo 8**) along the riverbank that can extend 150 feet into the river channel at low tide (**Photo 9**; HPEC 2012). Areas of forest and freshwater wetland also exist in small patches on the site. The Middlesex County Park System maintains and replants trees within the interior of the park (HPEC 2012). However, during the site visit, areas of established forests were observed along the northern edge of the park that are being encroached upon by invasive and native vines. The Middlesex County Park System does not currently have a program to maintain and preserve these forested areas (HPEC 2012).

4.1.5 Soil Drainage/Hydrology

Soils within Donaldson Park are primarily characterized as Rowland silt loam, which characteristically has 0 to 2% slopes and is frequently flooded (**FIGURE 7**) (**Photo 10**). This park receives a large volume of stormwater runoff from the surrounding developed areas, as evidenced by sediment observed on walking paths and scoured channels near the bank. There are two stormwater outlets (**Photos 11 & 12**). Scour channels were observed leading to the Raritan River at both of these locations. At the western end of the Raritan River bank in the park, significant erosion has led to a loss of approximately 15 feet of park over the past 10 to 15 years. In part this is due to mowing of plants and grasses to the edge of the riverbank (HPEC 2012). The riverbank is in need of increased stabilization - rip-rap is exposed in areas (**Photo 13**), and the few existing trees and scarce vegetation do not act to stabilize the riverbank.

4.1.6 Sea Level Rise

Donaldson Park is located in the historic floodplain of the Raritan River. A large portion of the site is vulnerable to SLR of two to three feet in elevation. The Park is generally very flat with low banks. Therefore, the site is prone to flooding, and potentially has higher vulnerability to even low rates of SLR. The northern portion of the site has slightly higher elevations, limiting SLR vulnerability to the southern half of the property.



Photo 8: Low tide reveals extensive mud and gravel flats



Photo 9: Shallow bank and erosion from tree roots



Photo 10: Insubstantial riverbank and gently sloping shoreline



Photo 11: Stormwater outlet



Photo 12: Channel leading stormwater outlet to Raritan River



Photo 13: Exposed rip-rap along shoreline





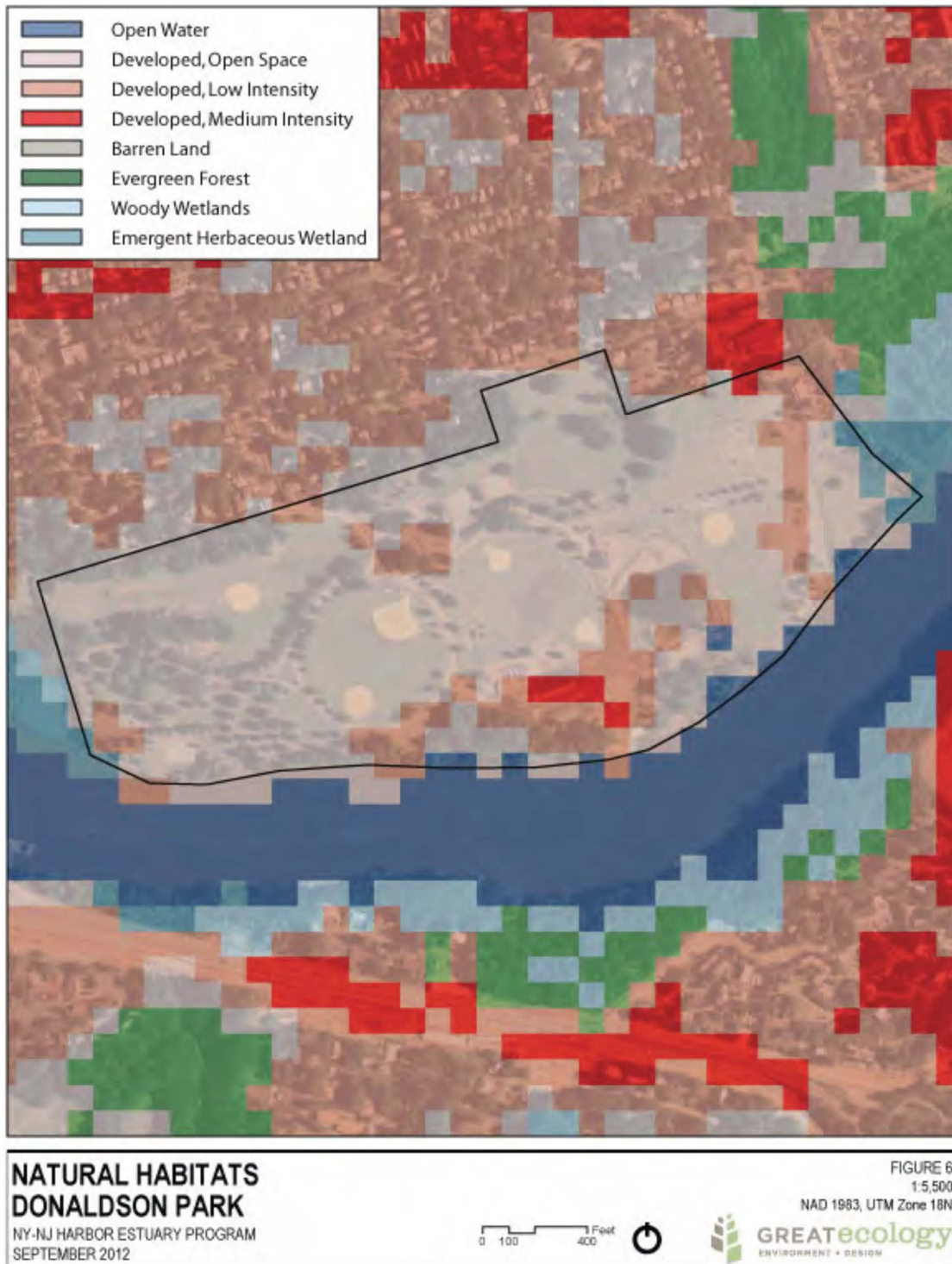
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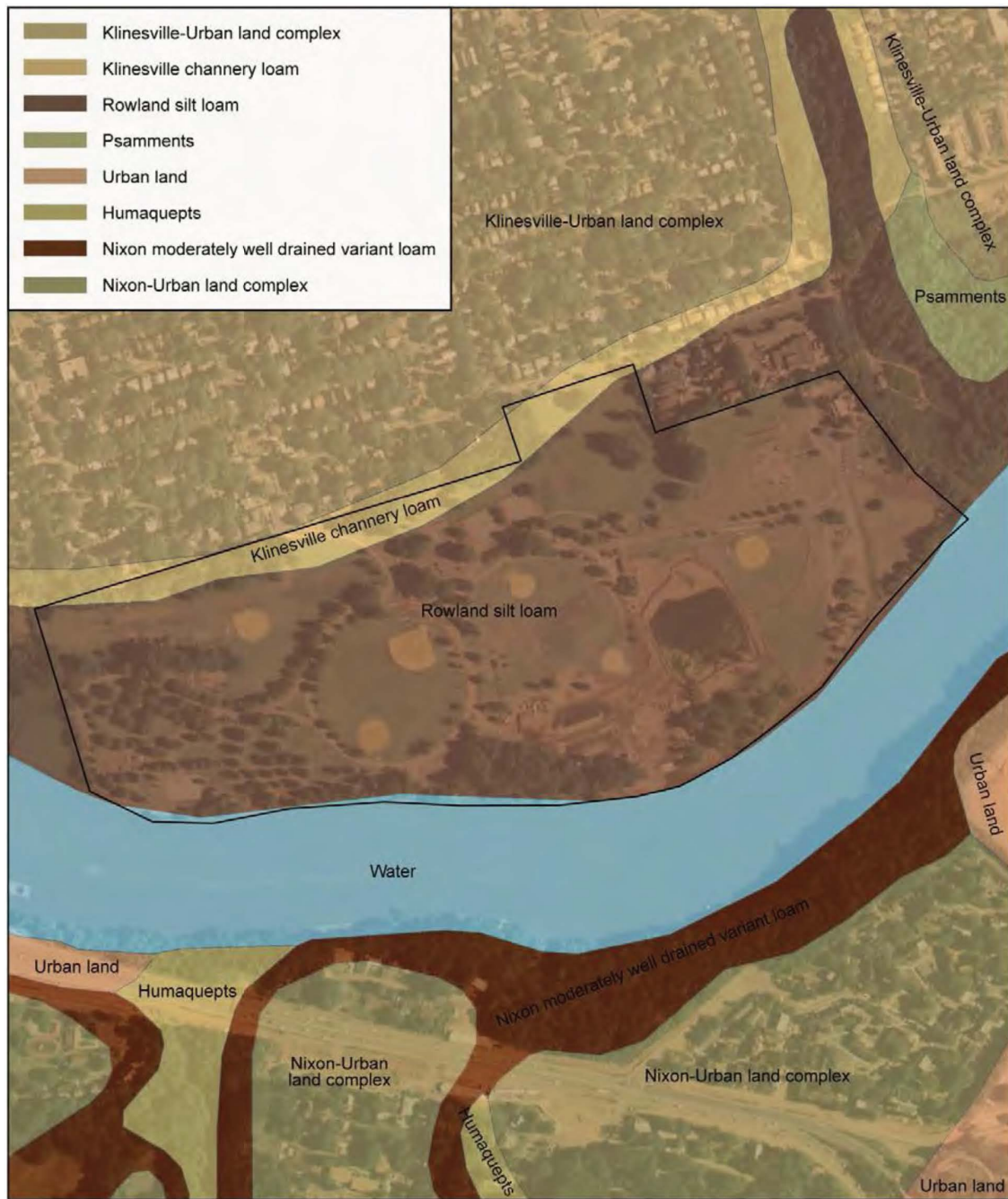
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**SOIL DRAINAGE/HYDROLOGY
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0 100 400 Feet



GREAtecology
ENVIRONMENT + DESIGN

FIGURE 7
1:5,500

NAD 1983, UTM Zone 18N

4.2 Old Bridge Park

Old Bridge Park is located in the town of Laurence Harbor on the edge of the Raritan Bay. It is closely abutted by a housing development to the south, and is located across the Bay from Staten Island, NY. A large wetland complex borders the site to the southeast (**FIGURE 8**).

Old Bridge Park (**Photo 14**) offers 1.3 miles of public access via walking and biking paths (**Photo 15**) along the Raritan Bay. **FIGURE 8** displays the various amenities of the park, including a small concession area, three fishing piers (**Photo 16**), three beaches (two open to the public), a performance gazebo (**Photo 17**), playground, and a boardwalk (**Photo 18**). The intertidal shore has small patches of healthy smooth cordgrass (*Spartina alterniflora*) and a thriving ribbed mussel population (*Aulacomya ater*; **Photos 19 & 20**). Great Ecology also observed woodchuck (*Marmota monax*), eastern cottontail (*Sylvilagus floridanus*), blue crab (*Callinectes sapidus*), and horseshoe crabs (*Limulus polyphemus*) utilizing the beach and bordering herbaceous habitat (**Photo 21**).

The site is also part of the Raritan Bay Slag Superfund site, and contains lead contamination on a portion of the site particularly the seawall, which is currently fenced off. The relationship between SLR and lead contamination is beyond the scope of this study, but the results will be shared and discussed with the EPA Superfund Office to highlight any potentially relevant concerns for future remediation.



Photo 14: Old Bridge Park



Photo 15: Lawn bisected by paved walking path



Photo 16: Fishing Pier



Photo 17: Performance Gazebo



Photo 18: Boardwalk



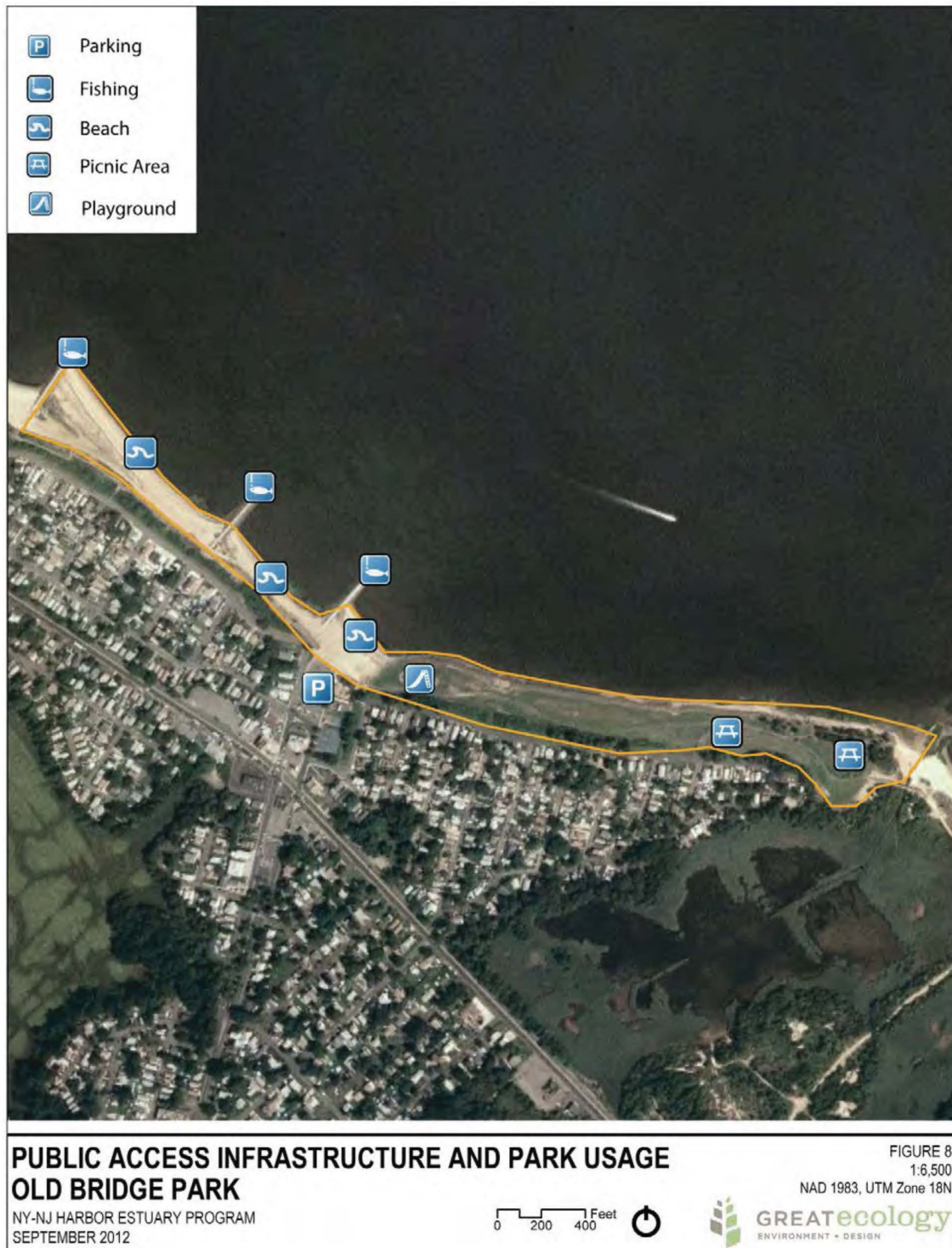
Photo 20: Thriving ribbed mussel population



Photo 19: Small patches of *Spartina alterniflora*



Photo 21: Horseshoe crab



4.2.1 Geomorphology

Old Bridge Park is primarily comprised of a grass lawn bisected by a paved walking path along the coast and seawall (**FIGURE 9**). There are also three beaches located within the park, increasing in size from east to west. The beach furthest to the east is contaminated with lead. This beach is fenced off from public access, along with the entire coastline from this point eastward (**Photo 22**). Each beach is separated by a pier and connects to the park via walking paths (**Photo 23**). A small strip of mudflat in the intertidal zone extends seaward from each beach and can be viewed at low tide (**FIGURE 9**). There are small areas of forested and shrubby upland habitat that border the lawn and act as a buffer between the park and the adjacent housing development (**Photo 24**). Fill was added to tidal wetlands, abutting a large seawall, to build the existing park. The elevation of Old Bridge Park ranges from eight (8) to twelve (12) feet above a small strip of intertidal shoreline and Raritan Bay waters.



Photo 26: Steep bank drop-off



Photo 27: Concession stand area

4.2.2 Relief (Percent Slope)

Old Bridge Park is relatively flat with a mean percent slope of approximately 4.3% (**FIGURE 10**; **Photo 25**). However, a significant bank has been built up along the shoreline from the seawall, with elevations ranging between eight and twelve feet (**Photo 26**). Elevations increase quickly toward the residential neighborhoods to the south of the park (**FIGURE 10**). The wetland complex to the southeast of the site is an area of relatively low elevation (**FIGURE 10**).

4.2.3 Flood-Prone (Low-Lying) Areas

There are no unconnected low-lying areas within the Old Bridge Park boundaries used in the GIS model.



Photo 22: Overlooking contaminated beach and seawall (on right)



Photo 23: Fishing pier



Photo 24: Gently sloped vegetative buffer to housing development



Photo 25: Walking trail and flat grass

However, **FIGURE 11** does depict low-lying areas in the adjacent wetland complex area where two ponds currently exist.

4.2.4 Natural Habitats

The large majority of Old Bridge Park is categorized as developed open space (**FIGURE 12**). These areas are dominated by herbaceous and grassland habitats. Small patches of low and medium intensity development (walking paths and concession stand; **Photos 27 & 28**) and smaller areas of open water and emergent herbaceous wetland also exist within Old Bridge Park (**FIGURE 12**).

4.2.5 Soil Drainage/Hydrology



Photo 28: Walking/biking path

The soils of Old Bridge Park are entirely characterized as excessively well-drained (psamment) soils (**FIGURE 13**). However, two different psamment soil characterizations occur on the site: naturally occurring psamment soils and psamment soils over waste substratum. Stormwater runoff likely drains through the park to the Raritan Bay, as the highway and surrounding development are located up-slope from Old Bridge Park. Great Ecology observed evidence of high-velocity stormwater runoff near the concession stand, flowing towards the Raritan Bay (**Photo 29**).

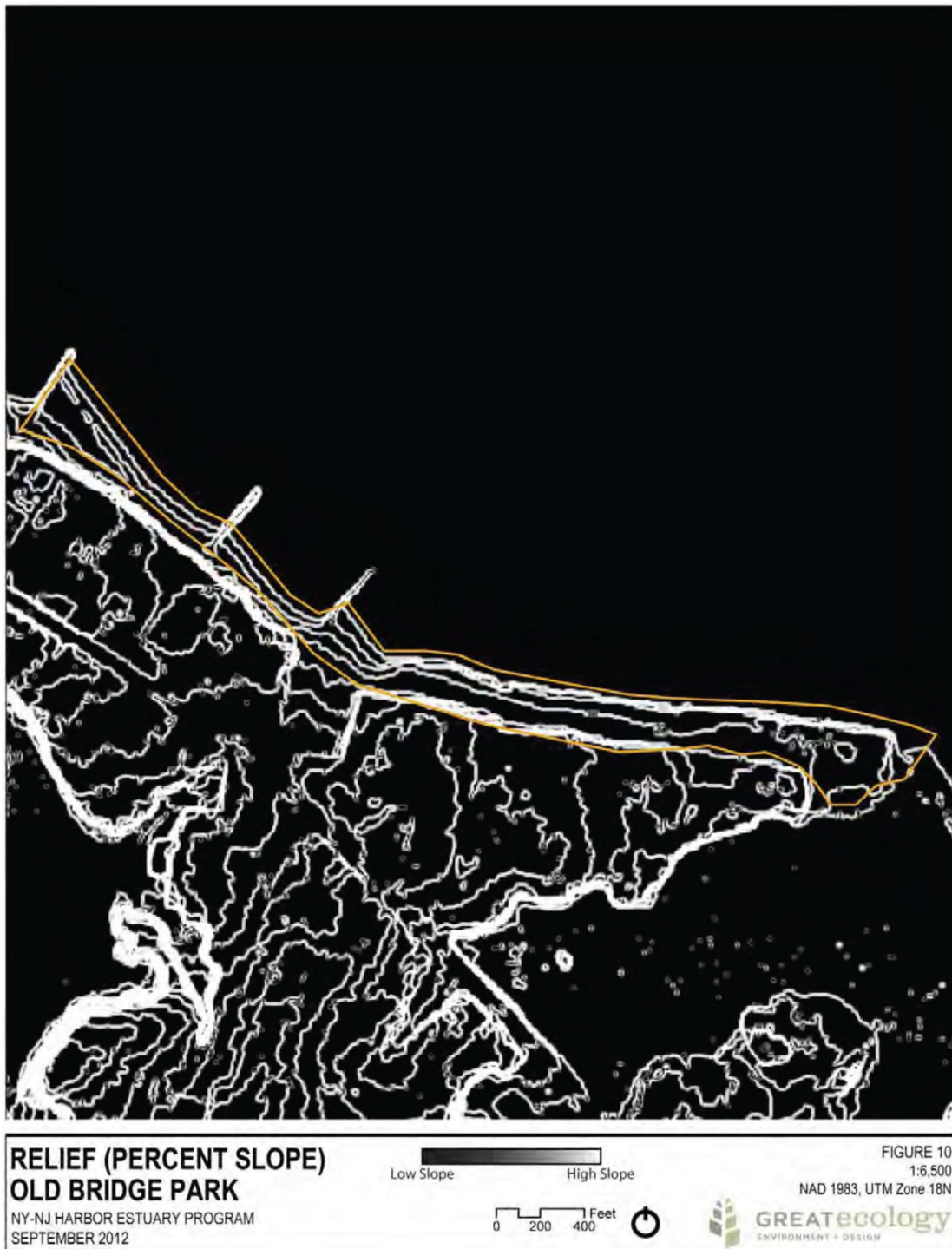
4.2.6 Sea Level Rise

Old Bridge Park is protected from inundation throughout much of its extent by a large rip-rap seawall. However, the seawall is discontinuous; there is a significant possibility for scouring behind the discontinuous sections of the seawall with increased sea level. Other areas of the site do not have a seawall at all. These areas are primarily naturally occurring beach front, with steep gradients immediately in-land. While the immediate unconsolidated beach area of the park may be vulnerable to SLR of two (2) feet or more, the majority of the site will not be affected. A large marsh complex immediately to the southeast of Old Bridge Park occurs in a wide depression. This area is very vulnerable to SLR if the marsh is not accreting fast enough to keep pace with the rise; however, surrounding areas have steep gradients. Any effects of SLR to these areas will be restricted to the marsh complex.



Photo 29: Stormwater runoff erosion channel near concession stand







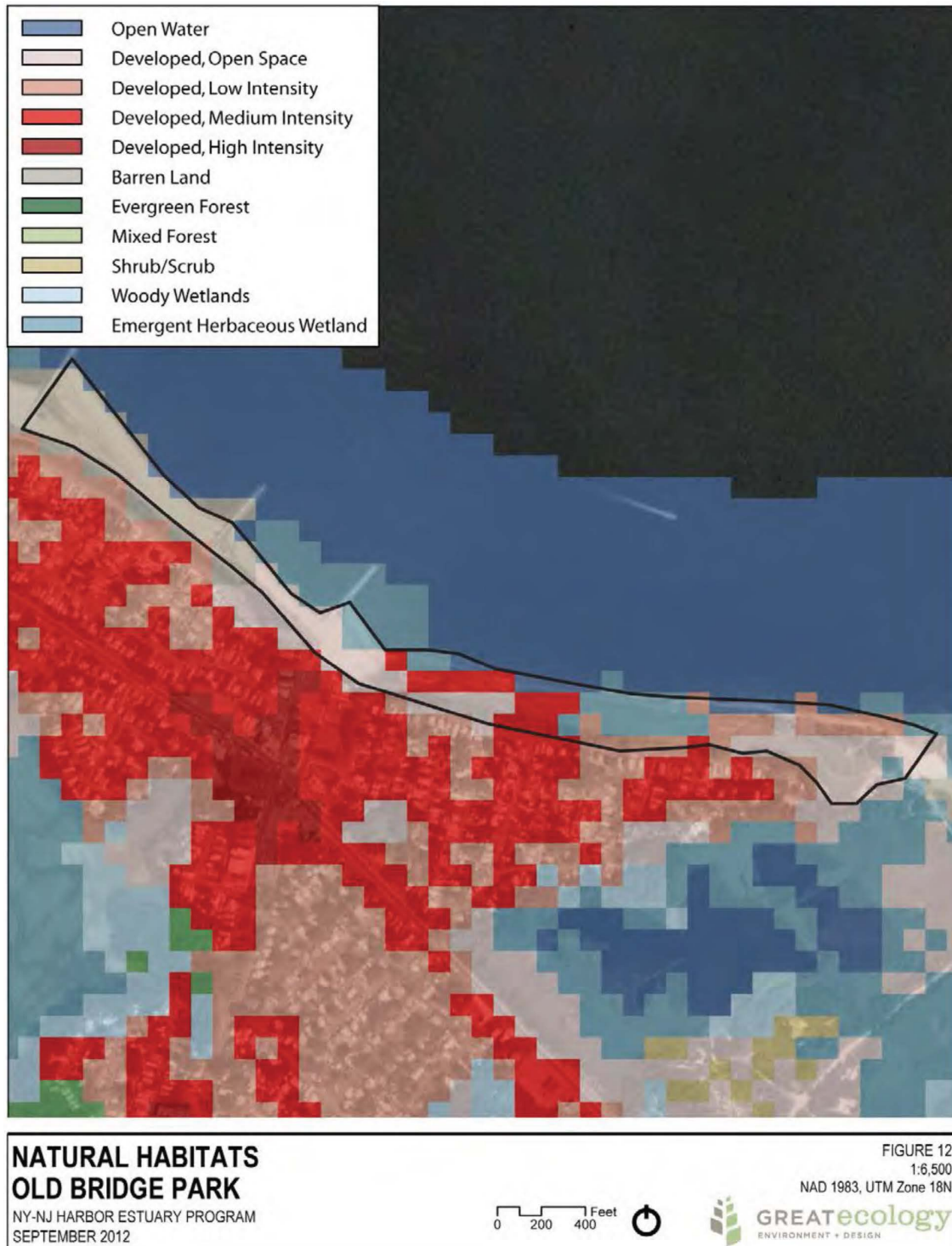




Photo 29: Woodbridge Waterfront Park

4.3 Woodbridge Waterfront Park

The future Woodbridge Waterfront Park is a 185-acre site located in Woodbridge Township, New Jersey (**Photo 29**). Historically, much of the site was comprised of tidal wetlands. However, the United States Army Corps of Engineers (USACE) filled approximately two thirds of the site via dredge material placement during channel deepening activities within the Raritan River during the 1940s and 1950s. This converted the tidal wetlands to stormwater-fed freshwater wetlands mainly vegetated by an invasive plant, common reed (*Phragmites australis*). The site is currently undergoing remediation and restoration activities. Wetland and open water mitigation efforts will create and restore a variety of wetland habitats. Mitigation and restoration activities include installation of more than 150 species of native herbaceous and woody plants (approximately 1,000,000 individual plants), removal of 51.9 acres of invasive *P. australis*, and removal of one (1) to five (5) acres of another invasive species, tree-of-heaven (*Ailanthus altissima*). Public access features, including trails, boardwalks, overlooks, bird blinds, and gathering spaces for environmental education, also will be constructed.

Upon its completion, the Woodbridge Waterfront Park will provide public access and preserve 90-acres of open space (**FIGURE 14**). The 90-acre park will be part of a permanent conservation easement. An access road and a network of paths will provide public access to the newly designed park. There will be two parking lots, one located just south of the barrier wall, and one at the southern end of the site (**FIGURE 14**). Trails will connect visitors to site amenities and habitat zones. A majority of the nature trails, made from crushed stone and compacted earth, will circumnavigate the wetland areas. As visitors walk along the trails, they will have opportunities to view wildlife and native plant communities, utilize the site for educational purposes, and observe the Raritan River.



4.3.1 Geomorphology

The mitigation plan, developed by Great Ecology, will enhance 33.5 acres of existing wetland habitats and create 9.7 acres of new wetland (**FIGURE 15**). The design will create new freshwater wetlands by converting areas of adjacent upland to wetland through topographical and hydrological modifications. Additional topographical modifications to the site will promote the establishment or restoration of salt marsh, forest, and upland habitat, as well as a freshwater pond (**FIGURE 15**). As part of the remediation, the northern section of the site will be elevated by several feet to a mean elevation greater than 13 feet (NAVD 1988). This will protect future development from flooding and SLR. Public access infrastructure will be constructed on higher elevation areas surrounding the freshwater and tidal wetlands of the site.

4.3.2 Relief (Percent Slope)

Grading for the final project will be similar to existing topography, except in areas of wetland creation. Topography onsite is gently sloping toward the Raritan River with elevations generally ranging from sea level to 21 feet (NAVD 1988) (**FIGURE 16**). The elevation immediately increases several feet from the salt marsh on the southern edge of the property along the bank of the Raritan River and continues to increase in elevation toward the northern edge of the property. Much of the site was historically under the tidal influence of the Raritan River; however, all areas of wetland below the central berm are now elevated many feet above sea level due to the deposition of dredge materials by the USACE. Mitigation wetlands will largely remain freshwater-influenced, except for the portion of restored tidal marsh at the southern end of the site along the Raritan River. The majority of the slopes are less than 10:1, which will help to prevent erosion and allow for wetland boundaries to shift under various hydrologic conditions.

4.3.3 Flood-Prone (Low-Lying) Areas

The majority of the future Woodbridge Waterfront Park is located within the floodplain of the Raritan River (**FIGURE 17**). As defined within the GIS model, 21.1 acres are unconnected low-lying areas ranging from -1.64 to 6.56 feet. However, the public access road entrance and high points throughout the trail network are outside of the flood-prone area. Additionally, two small ponds in the northern section of the Woodbridge Waterfront Park are classified at elevations below sea level in the NOAA LiDAR dataset. This classification is inaccurate. NOAA classified any open water areas as having -0.5 feet elevation. As a result the low-lying datasets and SLR variables within the CVI model incorrectly depict these ponds as highly vulnerable areas.

4.3.4 Natural Habitats

Mitigation activities will remove areas of *P. australis* and replant them with a variety of native vegetation, resulting in the establishment of wetland, upland, and open water habitat features interspersed across the site (**FIGURE 18**). Restoration activities will create or restore 2.9 acres of tidal wetlands, 44.2 acres of emergent freshwater wetlands (marsh, pond, forest, and scrub-shrub habitat types), 52.5 acres of upland buffer habitat (maritime forest, maritime meadow, maritime shrub, salt shrubland, and existing forest habitat types), and 7.0 acres of brackish meadow (**FIGURE 18**). The design specifies a robust and diverse assemblage of plant species with various inundation and salinity tolerances. This means that the plant communities should be able to respond, shift, and self-organize according to long-term water level changes.

4.3.5 Soil Drainage/Hydrology

After excavation of 18" of *P. australis* root mat material as part of the invasive species control plan, 18" of engineered planting media will be placed on site prior to vegetation establishment. Following excavation, contractors will place a manufactured planting medium throughout the mitigation area.

This will promote the establishment and growth of preferred vegetation. Planned soils are Sandy Loam, with low organic matter content (**FIGURE 19**). Outflow points are designed with limited hardscape, including small areas of rip-rap and pre-cast concrete, which should prevent against erosion and scour.

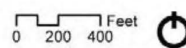
4.3.6 Sea Level Rise

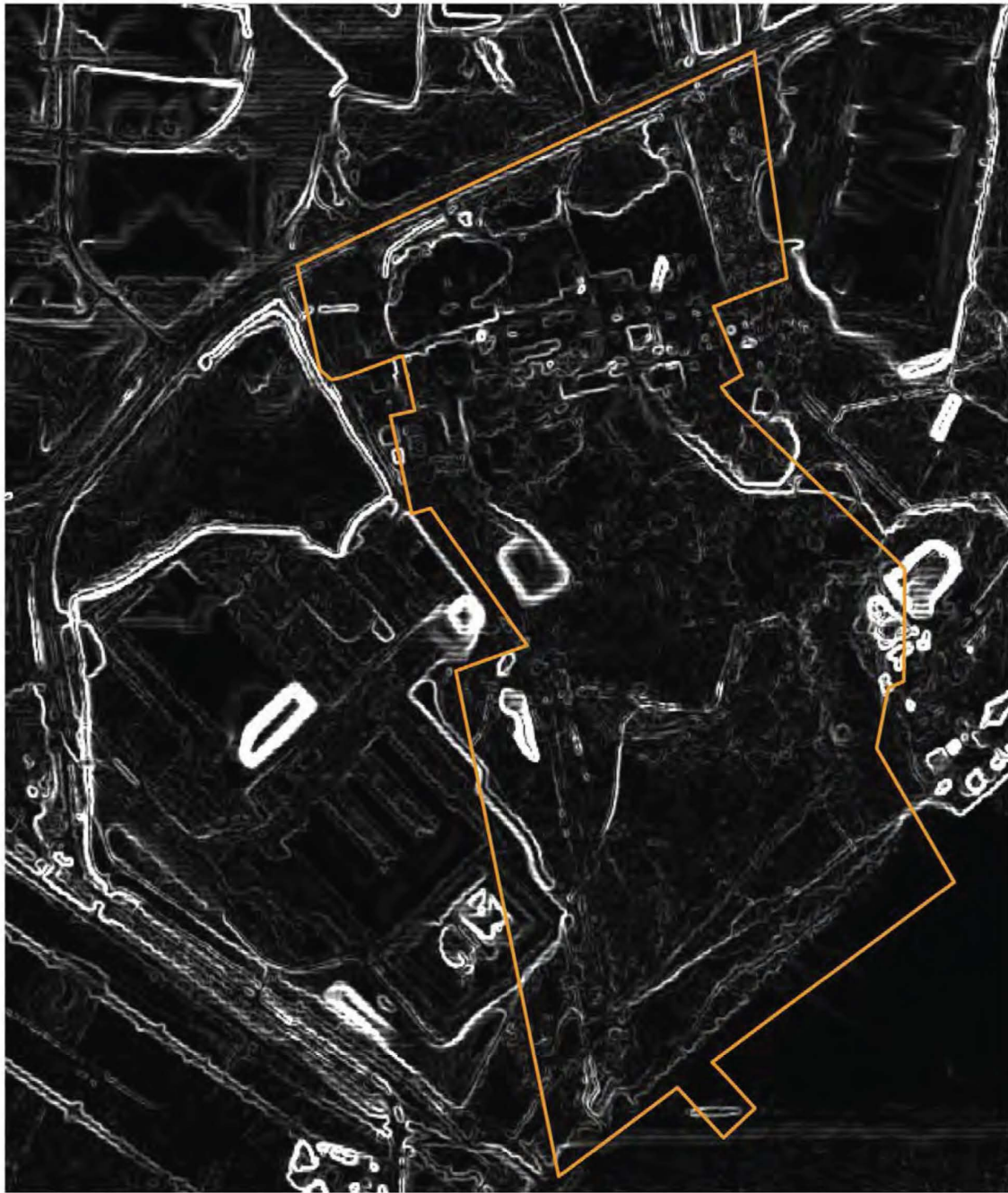
Large berms along the southern edge of Woodbridge Waterfront Park protect the site from SLR of less than four (4) feet. At five (5) feet of SLR, large portions of the southern half of the site are at risk of flooding. A tidally influenced creek on the eastern boundary of the property also is vulnerable to SLR, but this vulnerability is located at a significantly lower elevation (>4 feet) than the adjacent freshwater wetlands. NOAA SLR data show one of the freshwater ponds in the northern extent of the property as being extremely vulnerable to SLR. However, the proposed elevations of the completed construction work currently ongoing at Woodbridge Waterfront Park and the installation of a groundwater barrier wall will greatly reduce that risk.



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FIGURE 15
1:8,000
NAD 1983, UTM Zone 18N





RELIEF (PERCENT SLOPE)
WOODBIDGE PARK
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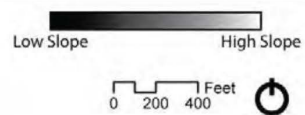


FIGURE 16
1:8,000
NAD 1983, UTM Zone 18N



**FLOOD-PRONE (LOW-LYING) AREAS
WOODBIDGE PARK**

NY-NJ HARBOR ESTUARY PROGRAM
SEPTEMBER 2012

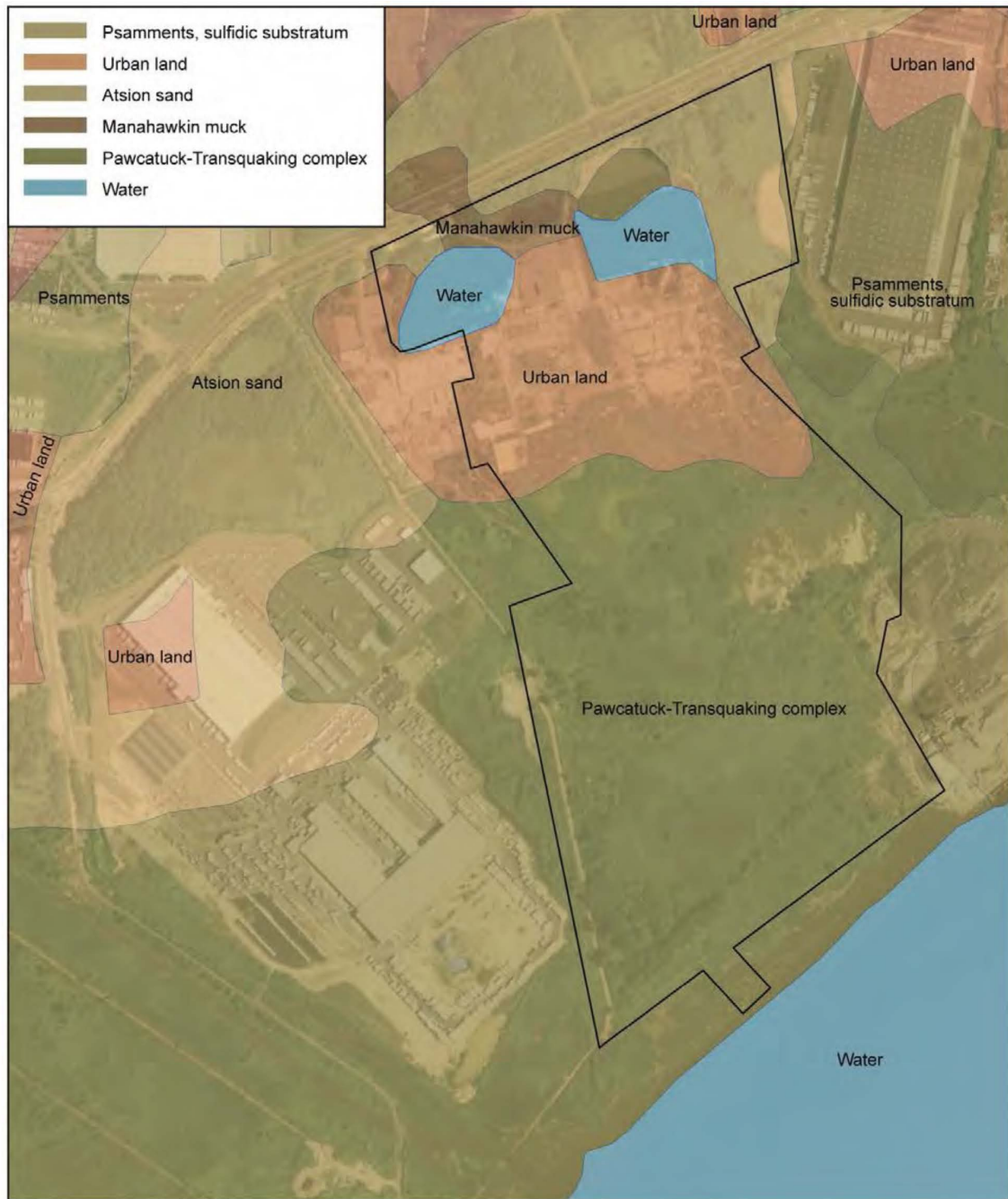
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FIGURE 17
1:5,500
NAD 1983, UTM Zone 18N



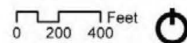


**SOIL DRAINAGE/HYDROLOGY
WOODBIDGE PARK**

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FIGURE 19
1:8,000

NAD 1983, UTM Zone 18N



4.4 Coastal Vulnerability Index Output

The CVI model outputs a 30-meter resolution raster dataset that denotes the mean of the six CVI variables per cell (**FIGURES 20 to 22**). Each cell of the dataset is 900 m² and symbolizes the CVI score of that geographic locale. The lowest possible value per cell is zero, which would denote an area with no data for any of the six CVI variables. The largest possible score of per cell is 30, which would represent an area with the maximum vulnerability score (5) for each of the six CVI variables included in the model.

The CVI output indicates that the majority of Donaldson Park is ranked as *more vulnerable*; however, surrounding areas are ranked as *less vulnerable* (**FIGURE 20**). The CVI output for Old Bridge Park ranks this site as *less to moderately vulnerable* with several *more vulnerable* areas toward the northwest section of the site (**FIGURE 21**). Similarly, the CVI output for the future Woodbridge Waterfront Park ranks much of the site as *less to moderately vulnerable* with some *more vulnerable* areas toward the northern and central areas of the site (**FIGURE 22**); however, the vulnerable areas at the northern end of the site are inaccurate due to errors in the NOAA LiDAR dataset.

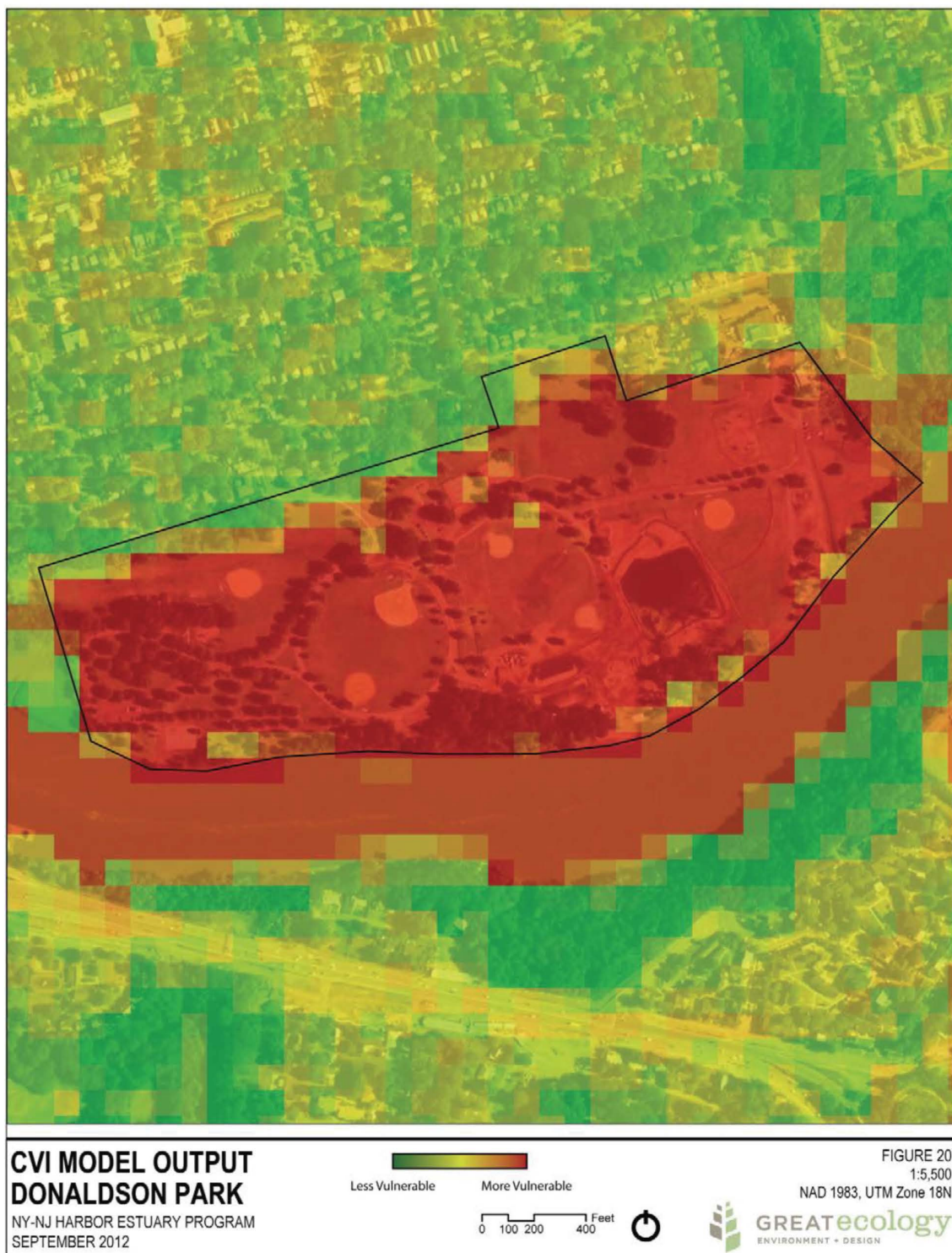
The mean CVI score for all three sites is 13.7 (standard deviation (SD): 2.6). The maximum CVI of the three sites is 24.0 (Donaldson Park) and the minimum is 4.0 (Woodbridge Waterfront Park). **FIGURE 23** depicts the maximum, minimum, mean, and standard deviations of CVI scores for all three sites.

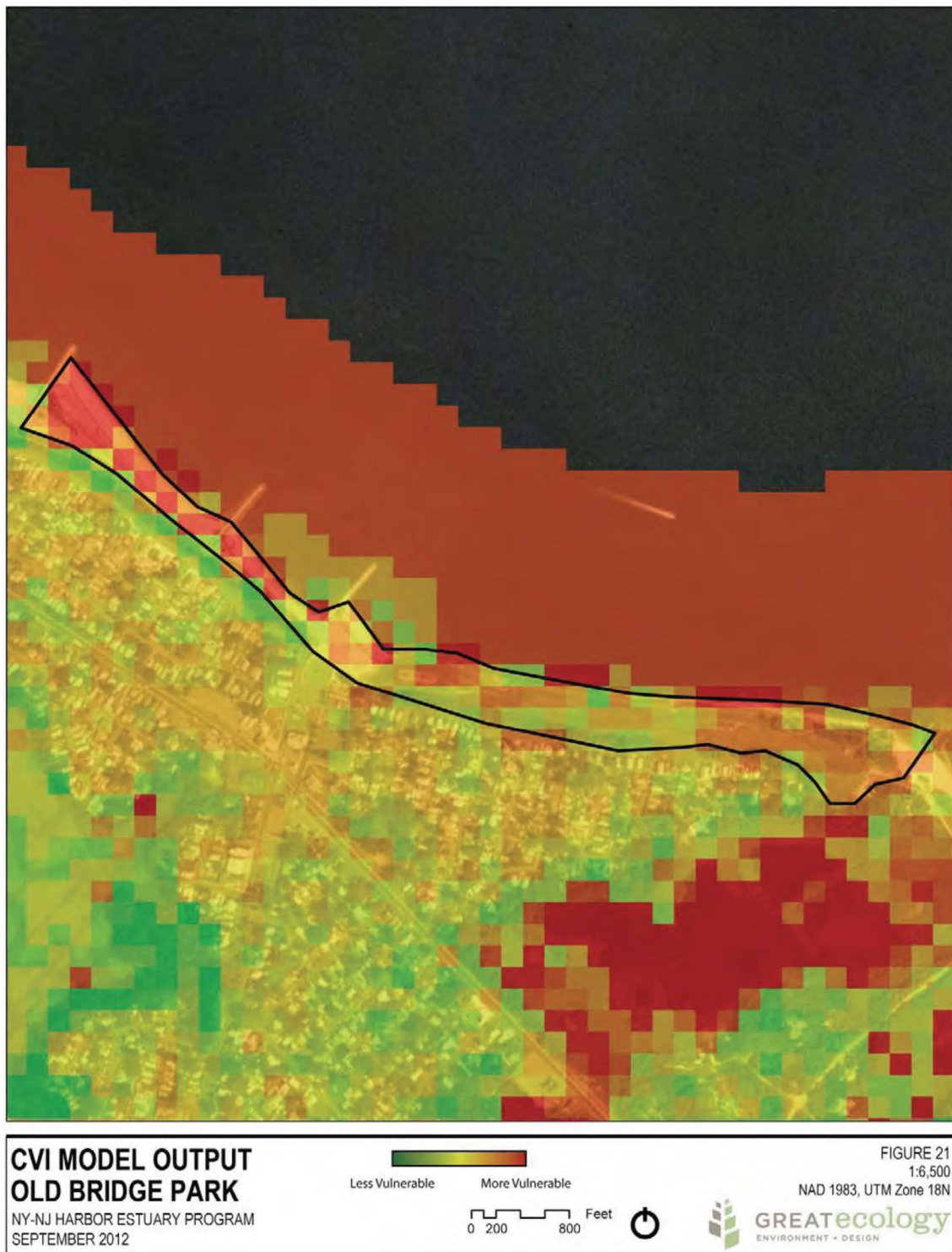
Donaldson Park has the greatest maximum CVI score of 24.0 for all sites, and the greatest minimum CVI score of 7.0 for all sites. The mean CVI score for Donaldson Park is 17.3 (SD: 2.2) (**FIGURE 23**).

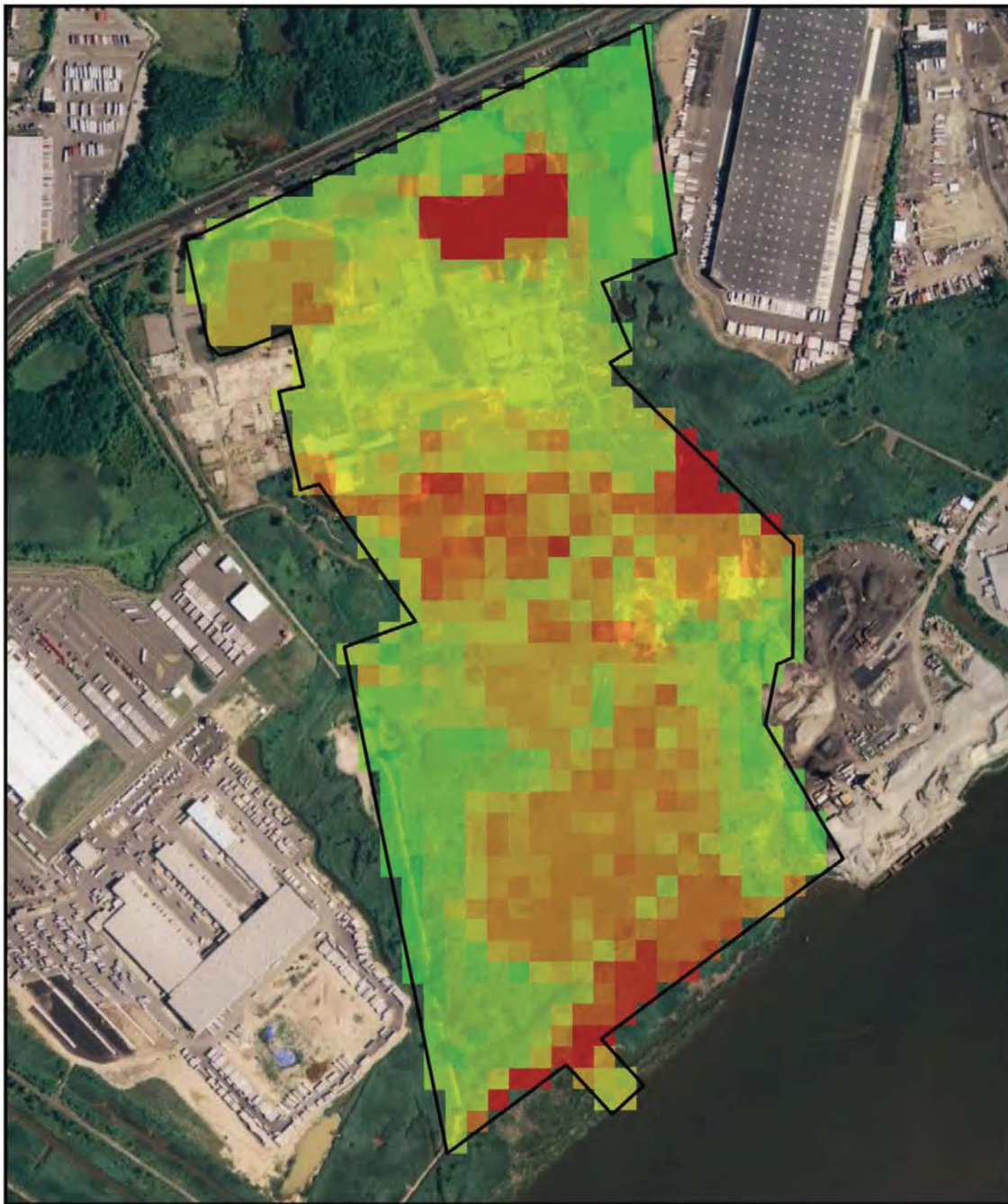
Old Bridge Park has a maximum CVI score of 22.0 and a minimum CVI score of 6.0. The mean CVI score for Old Bridge Park is 12.7 (SD: 3.0) (**FIGURE 23**).

Woodbridge Waterfront Park's maximum CVI score is 23.0 and its minimum CVI score is 4.0, the lowest of any site. The mean CVI score of Woodbridge Waterfront Park is 11.0 (SD: 3.1) (**FIGURE 23**).

The mean CVI score of Donaldson Park is statistically significantly greater ($P < 0.0001$) than that of the other two sites.





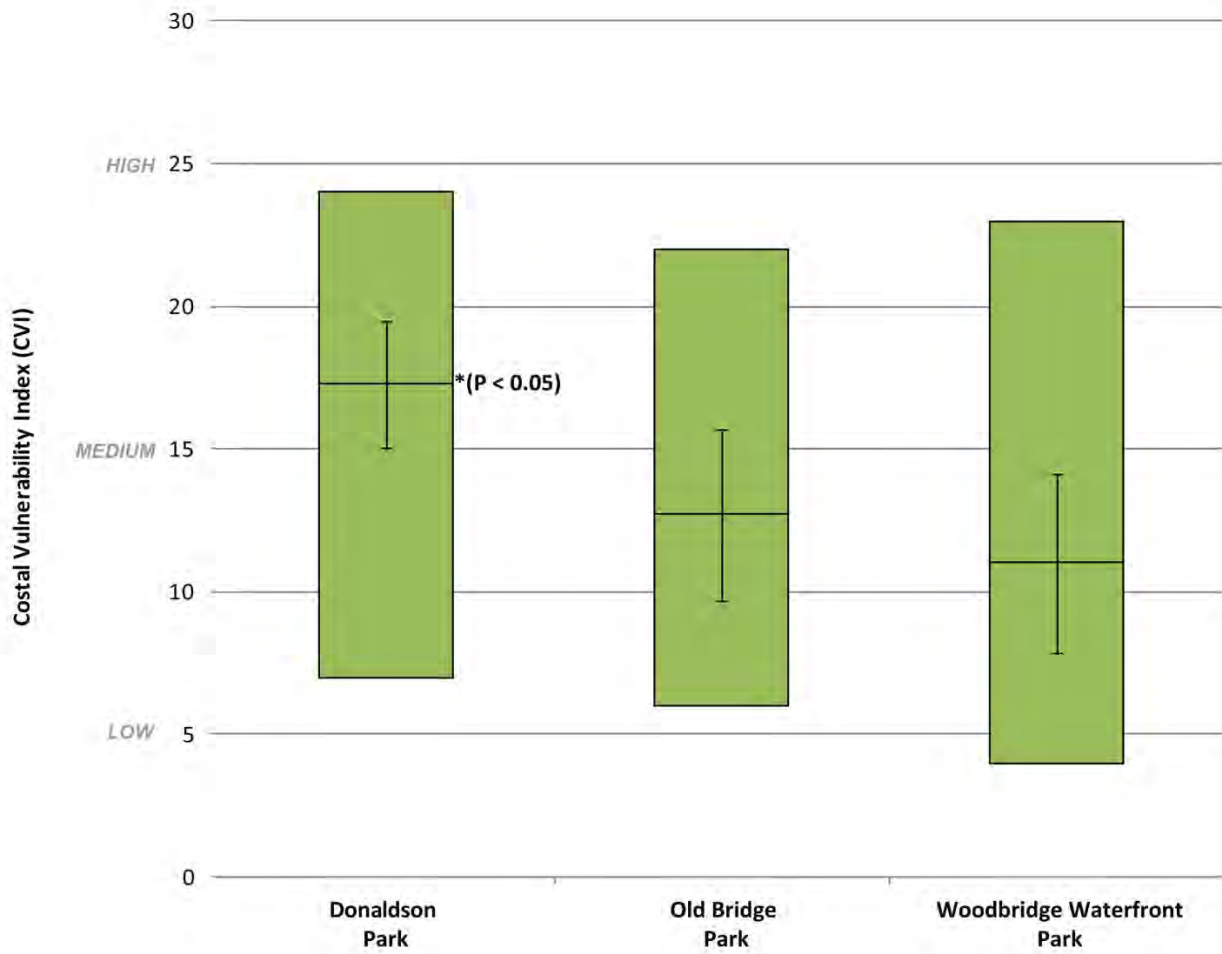


**CVI MODEL OUTPUT
WOODBIDGE PARK**
NY-NJ HARBOR ESTUARY PROGRAM
SEPTEMBER 2012

Less Vulnerable More Vulnerable

0 100 400 Feet





5 DISCUSSION

As stated, the NY-NJ Harbor Estuary is a complex ecological system in the middle of a major urban center. The NY-NJ Harbor Estuary will likely face substantial impacts to land, infrastructure, intertidal ecosystems, and livelihoods from SLR in the coming decades.

This study focused on the local impacts of sea level rise (SLR) on the NY-NJ Harbor Estuary, specifically the Raritan River Basin. Based on calculations developed by the Intergovernmental Panel on Climate Change (IPCC 2007) that exclude rapid ice melt scenarios, the New York Panel on Climate Change predicts between 7 and 12 inches of SLR by the 2050s and 12 to 23 inches of SLR by the 2080s. Those that include rapid ice melt scenarios project 5-10 and 41-55 inches, respectively (NYC Panel on Climate Change 2009). A rise in sea level of this magnitude can drastically alter the utility of public access spaces within the Raritan River Basin.

By employing a combination of field assessment and a Coastal Vulnerability Index at the site scale, potential impacts of SLR at each site were able to be estimated.

5.1.1 Site-Specific Assessments

The scale at which SLR analyses are conducted can influence the applicability of the data and how natural resource managers should interpret these results. For this study, data were analyzed at 30 meter by 30 meter raster cells (900 m²). The resolution of the final CVI is dependent upon the resolution of input variables. This resolution is appropriate to understand the impacts of SLR at the local (site) level because it allows for an evaluation of the individual variables that contribute to SLR for distinct areas (900 m²) of a site. Natural resource managers can evaluate SLR risks at two different spatial scales by examining both the CVI per cell and for the site as a whole, which is a useful tool to evaluate risks and prioritize efforts to limit the impacts of SLR.

5.1.2 Donaldson Park

Analysis of the geomorphology, relief, and low-lying areas (**FIGURES 3 to 5**) of Donaldson Park reveals that the park is a relatively homogeneous landscape with minimal topographic relief. Low scores for these three CVI variables contribute to a higher total CVI for Donaldson Park. Low-lying areas (mean 5-foot elevation) of the park currently retain storm water near the center of the park. Under SLR scenarios, these areas are likely to be vulnerable to SLR prior to the surrounding landscape. However, the mean elevation of the surrounding park is only 1.2 feet higher, so these areas should also be considered vulnerable to SLR scenarios.

Donaldson Park is mainly classified as developed, open space with small patches of natural habitats: forest, freshwater wetland, and mudflat (**FIGURE 6**). Mudflat habitat is located at the transition zone between the park and the Raritan River. Natural habitat composition determines the ability of a site to provide critical services normally associated with wetland habitats, including floodwater storage and wave energy attenuation. Most of the natural habitats in Donaldson Park do not provide these services, and therefore, are ranked as more vulnerable within the CVI model. However, soils of Donaldson Park are characterized as Rowland silt loam, which is a moderately well-drained soil (**FIGURE 7**). The ability of the soil to drain quickly ranks Donaldson Park as less vulnerable in the CVI model.

The CVI output for Donaldson Park is fairly homogeneous across the site, indicating that all areas of the site are equally vulnerable to SLR (**FIGURE 20**). The mean CVI for Donaldson Park is 17.3 out of a maximum score of 30, which is the highest value across all three sites and indicates this site is the most vulnerable to SLR (**FIGURE 23**). This difference is statistically significant ($P < 0.0001$),

indicating that efforts to mitigate the impacts of SLR are the most critical for Donaldson Park. A significant loss of land surface area due to inundation is possible.

5.1.3 Old Bridge Park

Old Bridge Park's geomorphology, relief, and low-lying areas (**FIGURES 9 to 11**) contribute to this park's resiliency to SLR under current climate change scenarios. A large (8 to 12 feet high) seawall separates the majority of Old Bridge Park from Raritan Bay. The three small beaches in the northwest portion of the site are not protected by a seawall; however, the elevation of the beaches is adequate to provide resiliency to SLR under current scenarios (**FIGURE 10**). South of the seawall and beaches, elevations increase fairly quickly, providing the park with further protection from elevated sea levels. Appropriate geomorphology, high relief and few low-lying areas, contribute to a lower CVI output for Old Bridge Park. However, an adjacent wetland complex to the park is relatively low-lying with minimal slope (relief), and could face impacts from SLR (**FIGURES 11 to 12**).

Natural habitats within Old Bridge Park are primarily characterized as developed, open space with small patches of moderate to highly-developed areas. There are also small patches of natural wetland habitat (**FIGURE 12**); however, they are not large enough to provide beneficial ecosystem services such as flood or stormwater storage and wave attenuation. Soils throughout the Old Bridge Park are classified as psamments, which are considered well-drained (**FIGURE 13**). Within the CVI model, psamment soils are considered to be the least vulnerable to SLR due to their ability to allow water to percolate through the soil profile quickly rather than pooling at the surface. Therefore, Old Bridge Park soils have low vulnerability within the CVI model.

The CVI output for Old Bridge Park demonstrates moderate vulnerability to SLR. The central and eastern portions of the park are moderately susceptible to SLR with small patches of cells indicating a slightly variable vulnerability (**FIGURE 21**). The western portion of the park, the small strip of beach beyond the seawall is more susceptible to SLR. This is likely because this area is at a slightly lower elevation and is not protected by the seawall, as do the central and eastern portions of the park. Additionally, the main access road to the site, Route 35, may be impacted by elevated sea levels. The mean CVI for Old Bridge Park is 12.7 out of total maximum score of 30 (**FIGURE 23**). Old Bridge Park has a lower mean CVI than Donaldson Park, but higher than Woodbridge Waterfront Park. However, the mean CVI for Old Bridge Park is not statistically different from that for Woodbridge Waterfront Park.

5.1.4 Woodbridge Waterfront Park

The CVI model analysis for Woodbridge Waterfront Park is based on Great Ecology's restoration plans for the park, which is currently undergoing remediation and mitigation construction. Great Ecology ran the CVI model on post-restoration conditions to determine potential SLR resilience measures in advance of the public opening, expected in 2015. Great Ecology created an interpolated DEM raster surface in GIS from the elevations on restoration plans. Low-Lying Areas and SLR variables within the CVI model were not available to model future conditions, as those variables rely on the NOAA LiDAR dataset, which is based on existing elevations. As there were no surrogate data for these variables, we used existing conditions and NOAA LiDAR data for calculation of the CVI.

Woodbridge Waterfront Park variables will undergo considerably changes during construction. The geomorphology, relief, and low-lying areas will be completely remodeled (**FIGURES 15 to 17**). During restoration, some portions of the site will decrease in elevation (e.g., conversion of upland habitat to emergent freshwater wetland); whereas, in other areas, the elevation will increase (e.g., filling of ponds for remedial purposes in the northern area of the site). These changes will dramatically affect the habitat structure and ecological function. The slope of this site gradually

increases from the Raritan River northward (**FIGURE 16**), providing greater resilience to SLR impacts. Three low-lying areas are depicted at the north end of the site (**FIGURE 17**), two of which are ponds that will likely be filled for remedial purposes to match the elevation of surrounding lands. The other low-lying area on the site is a tidally influenced stream (**FIGURE 17**), which will likely face impacts from SLR under current climate change scenarios.

The southern and central sections of Woodbridge Waterfront Park are primarily natural habitats consisting of tidal, freshwater, and forested wetland, freshwater pond, and upland forest and shrub habitats (**FIGURE 18**). These natural habitats contribute to a lower SLR vulnerability and CVI because of their ability to buffer SLR impacts by providing coastal services such as wave attenuation. Soils in the southern and central areas of Woodbridge Waterfront Park are classified as psamments (**FIGURE 19**), which provide soil drainage and contributes to a lower CVI for these sections of the park. The northern section of the park is characterized as urban space, and is slated for future development (**FIGURE 19**). This classification contributes to a higher CVI for this area of the park, due to its contribution to runoff and inability to infiltrate increased water levels associated with SLR.

Woodbridge Waterfront Park's CVI outputs are variable across the site, ranging from less to more vulnerable (**FIGURE 22**). The southern edge of the park, along the Raritan River, has moderate to high vulnerability to SLR. Areas north of this section have moderate vulnerability to SLR. Vulnerability along the southern edge and northward is mainly due to elevation, as these areas have the lowest on the site. Berms located adjacent to the tidally-influenced wetland areas may pose a threat to these habitats by preventing upland migration of these habitats with increased sea level; however, the majority of this area of the site is planned to have gentle slopes that could accommodate migration. Similarly, the area along the central eastern border, along the tidally-influenced stream, has a high vulnerability. The remaining areas, along the northern, eastern, and western borders of the park have the lowest vulnerability (**FIGURE 22**). An additional area in the northern section of the park is ranked as highly vulnerable; however, the elevations in this area will be increased similar to those of the surrounding landscape and will not likely face impacts from SLR. The mean CVI for Woodbridge Waterfront Park is 11.0 out of a maximum of 30 (**FIGURE 23**). Woodbridge Waterfront Park has the lowest score of all three project sites, which indicates that this park as a whole is not highly susceptible to impacts from SLR.

5.2 Site-Specific Recommendations

Based on data gathered during site assessments and results from the CVI model, the following are recommended for the three public access sites:

Donaldson Park

- Consider planting additional trees and dense native vegetation along the shoreline to promote soil and sediment stabilization and prevent further bank degradation and soil erosion (Section 4.1.4);
- Institute management practices that promote the maintenance of the shoreline habitats (e.g., limit mowing operations near these areas; Section 4.1.5) and
- Consider planting a dense vegetative border along development boundaries (e.g., stormwater outlets and pathways) to stem impacts and erosion from stormwater runoff at higher elevations (Sections 4.1.2 and 4.1.5).
- Consider locations and assess safety of above ground power lines currently at the edge of the park.
- Incorporate a likely longer-term loss of land surface area at Donaldson Park into planning and

maintenance decisions related to public access. When conducting regular maintenance or replacement of existing infrastructure (such as the paved parking lots near the riverbank) in low-lying areas, review any damage that has occurred as a result of flooding events and consider options for replacements at higher elevations to both prevent further damage and allow for upland migration of shoreline habitat.

Old Bridge Park

- Remediation of the existing seawall presents a unique opportunity to redesign the interface of the park with Raritan Bay. Alternatives to replacing the contaminated seawall, such as soft methods of bank stabilization and wetlands restoration, should be considered for the site to increase habitat value and further resilience to SLR (Section 4.2.4);
- Portions of Route 35, the main access road to the park, and the surrounding community of Laurence Harbor, may be impacted by SLR (**Figure 21**). Further analysis of this area should be completed and efforts to mitigate these impacts should be undertaken; and
- Groundwater and contaminant transport modeling should be incorporated into future park planning and coordinated with the EPA Superfund Office to understand the impacts of SLR for areas of the site that are contaminated by lead (Section 4.2).

Woodbridge Waterfront Park

- The public access component of this project has yet to be designed, beyond the conceptual level. Parking areas, trails, and boardwalks should have finished grades that are reflective of predicted SLR elevations. Additionally material choices will be influenced resistance to anticipated inundation and salinity, which will not be present at the time of construction.
- Incorporate plant species that tolerate of a wider range of conditions, to create resilience in the design;
- Identify opportunities for upland transition to provide SLR-related migration of coastal wetlands (Section 4.3.2); and
- Verify that SLR is considered in remedial activities to prevent exchange of contaminants between groundwater, soil, and sediments (Section 4.3.6).

5.3 Regional Assessment

Three public access sites along the Raritan River and Raritan Bay were analyzed to understand the potential impacts of SLR to public access sites within the NY-NJ Harbor Estuary and to demonstrate the use of the CVI model as an approach to assess these impacts at the site-specific scale. Historic and recent land uses have resulted in the loss or degradation of significant watershed resources within the Raritan River Basin, including wetlands and riparian zones located within the floodplain. These habitats provide important ecosystem functions, including habitat provision for wildlife, natural flood control, and water treatment (Shaw et al. 2009), and protection from erosion. The Raritan River significantly overflows its banks during and after large precipitation events. Flooding along the Raritan River's shorelines is common and can result in costly damages for property owners and municipalities. The CVI model captures at a coarse level whether or not the site is protected by these functions through noting the presence or absence of these habitats. Maintaining and restoring natural wetland and riparian zone habitat is important to ensure that riverine ecosystems provide

these critical functions, as these impacts will likely have a pronounced impact as sea level continues to rise.

Elevation is the most critical consideration in analyzing the vulnerability of a given site to SLR. Elevation is considered in three of the six variables within our CVI model: Relief (percent slope), Low-Lying Areas, and Sea Level Rise. Areas with low elevation, and without significant berms or seawalls, are highly susceptible to SLR. Based on current projections (IPCC 2007), areas that are within 12 inches of the current sea level will be regularly flooded within 40 years; areas within 23 inches of the current sea level will be inundated within 70 years. These projections do not include rapid ice melt scenarios, which could expedite these timelines (IPCC 2007).

The impacts of SLR are particularly important for public access sites within the NY-NJ Harbor Estuary because public access to the waterfront is currently limited. Access is likely to become increasingly limited as areas are damaged or flooded. In addition, municipal and federal capital for repair and restoration of these areas may be spread across many locations impacted by SLR. For areas like Old Bridge Park and Woodbridge Waterfront Park, concerns are not as great because these sites are located at a higher elevation. Smaller areas within these parks that are at lower elevations can be managed to limit the impacts from SLR. Sites at a lower elevation, such as Donaldson Park, will face greater impacts from SLR. Areas of similar elevation will be inundated more frequently and expansively because of their position in the landscape and lack of topographic relief.

5.4 *Regional Recommendations*

An important consideration for public access sites within this region is planning for existing and future infrastructure. Parking areas, public access roads, walking/biking trails, boat ramps, and docks are often found at or near the shoreline of these locations. Structures, including pavilions, picnic tables, park benches, and restrooms, may also be impacted by flooding associated with SLR if located at low-lying areas. Additionally, municipal infrastructure (e.g., sewer outfalls) may require modification to prevent hydrologic connection with elevated sea levels. Damage or loss of this infrastructure could result in significant costs to municipalities to repair or replace them. Additionally, their loss would mean that the public might lose access to these sites due to safety concerns. Future infrastructure should be constructed in lower susceptible areas to prevent these problems. Planning for existing infrastructure should include migration to less vulnerable areas, retrofitting infrastructure (e.g., install backflow prevention to existing stormwater outfalls), or developing protection measures to prevent or limit the impacts of SLR.

The influence of SLR on polluted environments poses another potential risk to coastal areas within the NY-NJ Harbor Estuary. Pollutants from stormwater runoff from farms and urban development; nitrogen, phosphorus and other discharges from wastewater treatment plants; and contamination from past and presently operating industrial facilities have the potential to enter the estuary (Shaw et al. 2009). Rising sea levels will result in greater hydrologic connectivity to soils and groundwater, and, if these areas contain pollutants, SLR will provide a pathway for these contaminants to spread and reach waters of the NY-NJ Harbor Estuary. The New Jersey Department of Environmental Protection (NJDEP) identifies sites of groundwater contamination and the geographic extent for specific contaminant levels that have been exceeded (NJDEP 2007). This information and similar types of contamination data should be used to identify priority contaminated sites for SLR resiliency measures, and could be a component within an updated CVI model for this area. If the potential for hydrologic connectivity to pollutants is identified, efforts could be taken to mitigate for these risks ahead of time.

Evaluating the impacts of SLR to public access sites in the NY-NJ Harbor Estuary requires natural resource managers and planners to identify, mitigate, and plan for these risks in advance. The CVI model used in this study is an excellent method to identify these risks because it incorporates on-the-ground site assessments with regionally available GIS data to evaluate areas on an ecologically meaningful scale. It is important to understand the potential impacts of SLR at the site level to adequately mitigate and plan for SLR risks. Although a major part of projecting SLR impacts involves desktop-based analyses, this information must be verified through site visits and interpreted by local professionals to truly understand the scope and breadth of impacts to an individual site.

6 CONCLUSIONS

In this study, a CVI model (adapted from Tallis et al. 2011) was used to assess SLR impacts in the NY-NJ Harbor Estuary for three public access sites along the Raritan River and Raritan Bay. The six CVI model variables we examined were geomorphology, relief, low-lying areas, natural habitats, soil type, and projected sea level rise. Three of these variables (relief, low-lying areas, and projected sea level rise) are related to elevation, indicating the importance of topography and landscape position of a site in determining its vulnerability to SLR. It is important to note that the potential impacts of flooding associated with storm surge and heavy rain events (more likely a concern in upstream areas, such as Donaldson Park) were not assessed in this study. Mapping projected sea level rise can help indicate the most likely vulnerable low-lying areas, but further SLOSH-type storm surge modeling would need to be conducted to get a fine-scale sense of this vulnerability.

There is often little that can be done to change the elevation of existing public access sites; however, planning for infrastructure, access pathways, and future development can utilize this information to make informed decisions that will reduce the impacts of SLR. In addition, removing barriers to upland wetland habitat migration should be considered to maintain the important functions that these habitats provide. Soil type and natural habitat are critical components that can be modified in public access sites to mitigate SLR impacts. Well-drained soils, as well as natural wetland and riparian habitats, provide the ability to process water better than soils that are high in clay or developed, open spaces, such as manicured lawns. Wetland and riparian communities can attenuate wave action and act to store flood waters, reducing the impacts of flooding or coastal storms to public access spaces.

The CVI model used in this study is an excellent method to identify potential SLR impacts because it incorporates on-the-ground site assessments with regionally available GIS data to evaluate areas on an ecologically meaningful scale. Our CVI model was able to determine which of the three sites, and even which areas of these sites, are most susceptible to SLR.

The CVI model approach used in this study is a relatively simple and efficient method that can provide coastal communities with the information needed to mitigate and plan for SLR. This CVI model serves as a useful and reusable framework for assessing SLR vulnerability and resilience at the local (site) geographical scale. The CVI model can be easily adapted to assess additional risks by incorporating additional variables, such as hydrologic connectivity to contaminated areas or by weighting specific variables within the model that are of greater concern for a particular site.

It is important for local municipalities, state governments and agencies, non-governmental organizations, and stakeholder groups to work together to face the challenges of SLR. The impacts must be determined at the site level, but coordination in planning to mitigate these impacts can be coordinated at the landscape level. Public engagement also can help to gather support for these types of projects, especially as they affect coastal infrastructure and natural resources at the local level. By considering SLR before sites are impacted, risks can be mitigated through planning integration, disaster preparedness, and hazard mitigation to improve the resiliency of public access sites throughout the NY-NJ Harbor Estuary. If resilience is not built into the way the estuary is protected, restored, and managed, these areas and the resources they support are likely to be compromised and possibly lost.

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